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ENGINEERING SUPPORT PROGRAM

WO-LT-0044

Bamyan Valley Electrical Transmission & Distribution (T&D) System Technical Design Services

October 23, 2011

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October 23, 2011

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[redacted]

Enclosed is the report for the Bamyan Valley Electrical Transmission & Distribution (T&D) System Design Technical Services.

I look forward to meeting with you to discuss this report.

Respectfully,

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Tetra Tech, Inc.

Cc: [redacted] (USAID-OIEE)

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AFGHANISTAN ENGINEERING SUPPORT PROGRAM

WO-LT-0044
BAMYAN VALLEY ELECTRICAL TRANSMISSION & DISTRIBUTION (T&D) SYSTEM TECHNICAL DESIGN SERVICES

October 23, 2011

Table of Contents

1.0 Executive Summary

As directed under Task 1 of WO-LT-0044 Statement of Work (SOW), this report provides a thorough Technical Review of:

- The preliminary design documents (which include the Distribution Design Report and Transmission and Distribution Design drawings) provided by USAID (as prepared by IRG-ACEP).
- Commentary as to the feasibility of adapting the preliminary transmission and distribution design to support the proposed NZAID 1MW solar power generation project.
- A review of the AKF preliminary design documents to begin evaluating the possibility of integrating the AKF distribution system with the proposed USAID transmission and distribution system design.

In order for the electrical system to be as flexible as possible, so that any and all power sources (in any combination) could be used to match the need (load) at a given time the preference is for the power sources to be synchronized (into one system) onto the same power grid. Having "islands" of power is generally the least preferable way to operate.

The report will address the accuracy and completeness of the design as presented and will include commentary on the:

- Load Forecasting
- Electrical Design
- Mechanical Design Details
- Environmental Impact and Mitigation

1.1 Load Forecasting

This is always the most difficult task as the estimated load can vary from as little as 200W per household (by AKF) to as high as 1300W (by ADB). Since the electrical generation will not be an "on demand" hydropower plant, but will instead be a "stored energy" system of batteries charged by a photovoltaic system, the review includes an energy consumption calculation in kWh.

The conclusion is that the 1 MW photovoltaic should be able to provide power for most of the 24 villages for most of the year, unless the typical usage is higher than estimated, and if the AKF design takes care of the remaining 4 villages.

1.2 Electrical Design

The ACEP design was conceived around the idea that each customer would have a special meter and purchase a prepay card to purchase electricity. Since the AKF design does not presently include pre-pay meters for the Bazaar area or the four adjoining villages, the pre-pay meters in the ACEP design should probably be excluded during Task #2. In addition to this:

- ➢ The designs (ACEP, AKF, and NZAID proposal) were all conceived as separate and uncoordinated efforts, without taking into account how or where they were to be joined together, and so further detailed design analysis (in Task #2) will have to be performed to determine:

    - If a substation design will need to be included in Task #2 to connect the NZAID photovoltaic system to the ACEP distribution system
    - If the ACEP and AKF systems will normally be operated as islands.
    - What additional equipment (transformers and controls) would be required to synchronize the 480 volt AKF generator(s) with the NZAID photovoltaic system?
    - If the AKF generators are derated properly for the load at this altitude.
    - Distribution system design scope will need to be determined in Task #2 because the ACEP distribution drawings do not provide customer connection details.
- AKF and Tetra Tech design teams will need to coordinate with each other during the Task 2 design stage.

1.3 Mechanical Design

The ACEP drawing details are either in PDF form, or are made to be reproduced on large paper sizes that are not commonly available in Afghanistan. Therefore, all of the design will need to be redrawn, and there is some conflicting information or lack of detail that will need to be flushed out. Also the pole design standards have changed for DABS, and so Task #2 will require that the proper pole is selected and used in the final design.

If all parties agree to share information, then the AKF and NZAID designs should be able to be integrated into the ACEP transmission and distribution design.

1.4 Environment Impact

From the ACEP Report - The recommendations coming from DAFA's Archaeological Survey were followed carefully and the modified design introduces the required changes to the line routes, as shown in Annexes A (Overall Alignment Map) and B (Primary Lines detailed design Drawings). Also:

- The conclusions excerpted from the cited Archeological Survey Report include statement such as: "*Indeed, the project in its primary layout was already well planned. However, USAID and ACEP took the effort to consult an archaeologist to improve their decisions" "…We want to stress that from a purely archaeological view, the pole is the least intrusive installation" "…If the opponents to an electric project in Bâmiyân have gone in the valley in recent years, they have seen that there are already unapproved electrical projects in almost every village there and that the aesthetic quality of the valley already suffers because of a lack of a serious and unified project. The Topchi Small Hydro Project proposes to conduct this unification in a respectful way. In our opinion, if this project is not allowed, we predict that Bâmiyân will acquire electricity by more damaging means. It is unlikely that future projects proposed by contractors or private individuals will be as respectful and diligent as USAID and ACEP."*
- The ACEP design considers the protection of UNESCO property zones (core and buffer zones) subject to the distribution lines construction activity.

The AKF and NZAID designs will need to be as respectful and diligent as shown in the ACEP design to insure that the Historical and Cultural Heritage of Bamyan is preserved.

2.0 Detailed Technical Review

2.1 Load Forecasting

The power generation station has changed from a hydropower plant (that does not depend on stored electrical energy) to a photovoltaic system that must charge batteries, so the method of determining how viable an option it is requires a different set of calculations.

The amount of kWh available to be delivered during the year will vary by 300% during the year, with June being the highest average month, and December being the lowest average month.

Also since the usage in an area such as this will not really be known until the connections are made, it was decided that calculations should be made that use different assumptions (high usage or low usage) to understand the possible ramifications on the design. Therefore:

- Using High Watt hour Usage Consumer Assumptions
  - The high watt hour usage consumer calculations (Appendices A, B, and C) indicate that:
    - Small houses in villages will consume 1,227Wh daily
    - Small houses in city will consume 1,770Wh daily
    - Large houses (from ACEP report) in city will consume 6,567Wh daily
  - If 100% consumer connection to the power grid is achieved:
    - In December only Bamyan city can receive power
    - In June (when the most energy is produced) all but perhaps four villages would be able to receive power.
      - In our example we assumed Topchi, Ahangaran, Hajdar, and Chabdara would not receive energy; however it is more likely that this selection would change frequently so that a village does not feel slighted.
  - This is a very theoretical approach and is utilized to begin the analysis; however it is much more likely that due to financial constraint and/or distance to the utility grid that quite a few households will elect or not be able to connect. If an estimate of 25% actually connected and using electricity is utilized, then it is possible (but not certain) that all 24 villages could have power available all year.

- Using Low Watt hour Usage Consumer Assumptions
  - The low watt hour usage calculations (Appendices D, E, and F) indicate that:
    - Small houses in villages will consume 532Wh daily
    - Small houses in city will consume 1,163Wh daily
    - Large houses (from ACEP report) in city will consume 6,567Wh daily
  - If 100% consumer connection to power grid is achieved:
    - In this assumption for six months of the year all villages can receive energy.
    - With these assumptions, as high as 50% of the consumers could be connected and it is possible that all 24 villages could have power available all year.

Although both calculations indicate that there is a possibility that all 24 villages would have electricity available all year long, this is only on average, because there will sooner or later be consecutive cloudy days when the batteries will not receive enough of a charge to provide much power.

Undoubtedly issues could be taken with any method and assumptions that are made to try and make a logical decision as to the amount of energy that would be used and the viability of bringing electricity to such a location. See Appendix G for an example of a third party that came up with very similar conclusions.

For all of the above reasons it is strongly suggested that load shedding options should be included in the performance of a Task #2 design.

Other notes pertaining to Load Forecasting:

- The AKF and ACEP designs overlap each other on 2 villages that they serve. Since the AKF design likely has more spare capacity these were excluded from the ACEP load profile.
- The final functioning system will need to include some method of load control because:
  - The availability of generating capacity (in kW and kWh) will vary widely with the season.
  - The demand in kW and KWh will vary with the season, time of day, and will likely increase each year.
- According to the New Zealand Bamyan Infrastructure Program Energy report, demand expectations for residential buildings in Bamyan for the first year will be 1,310MWh/year (3,589kWh/day) and for the fifth year will be 1,657MWh/year (4,539kWh/day). In the ACEP report, monthly energy consumptions for Class 1 type residential buildings (small houses) is 40kWh (1,315 Wh/day) and for Class 2 type residential buildings (large houses) is 200kWh (6,567Wh/day).
- This reports energy consumption estimate also uses the ACEP report Table 2-1 which includes residential buildings, but does not include industrial, commercial, NGOs, or GOs.
- Street lights were not included in this calculation.
- Two of the villages in the list, Zargadan and Jograkhel, are assumed to be powered by AKDN.
- The average insolation rate in Bamyan varies during the year from 2.53 kWh/m^2/day minimum in December to 7.78 kWh/m^2/day maximum in June. For example; a 1kW photovoltaic system would daily produce 2.53 kWh of energy in December and 7.78 kWh of energy in June.
- Because the system will consist of inverters, batteries, wires, and modules the efficiency of the system will not be 100%. We assume that the efficiency for the total system is about 65% (85% for batteries, 85% for modules, 96% for inverters, and 96% for the copper loss).
- Therefore a 1MW peak photovoltaic system will on average have a daily production of 2.53 x1000kWx 0.65 = 1645 kWh of energy in December, and it will on average have a daily production of 7.78 x 1000x 0.65= 5,057 kWh of energy in June.
- Daily energy consumption for:
  - The small houses in the villages were obtained by assuming that there are eight rooms in the houses consisting of a living room, kitchen, bedroom, guest bedroom, bathroom, animal holding room, storage 1 for animal food, and storage 2 for wood. In the village house every other house will have a television set, and each house will have an electronic device like a radio, tape player, video player, etc.
  - For small houses in the city of Bamyan were obtained by also assuming that each bedroom and living room has a ceiling fan.

- To create a high and low scenario either 15W or 60W lighting fixtures were utilized in the calculation.
- For the large houses in the city of Bamyan we used the ACEP assumption (in Table 2-5) of 200kWh/month in our calculations which is equal to 6,576Wh/day.

2.2 The Electrical Design

2.2.1 The ACEP Design

The basic ACEP design is usable and can be used as an outline for continuing the design if Task #2 is approved. The fact that the photovoltaic system is in a different location than the originally designed hydropower plant will of course drive modifications to the design. It will also be desirable to attempt to consider how the system might be connected to the NEPS transmission system (through a substation) in the future. Also the CAD design documents need to be redrawn and reduced in size to accommodate the more commonly available printable paper sizes.

Below is a list of design details and changes to address in Task #2:

- Transformers need to be consistently named on the Primary and Secondary drawings.
- The exact size and type of each transformer needs to be determined.
- The conductor size, route, and phasing needs to be consistent on the Primary and Secondary drawings.
- The routing of overhead lines between the Primary and Secondary drawings must be the same.
- Connecting the NZAID's photovoltaic system into the ACEP transmission lines and determining what additional equipment will be required will have to be addressed.
- The specifications for components will need to be confirmed as consistent with DABS most recent preferences.
- Not all villages are shown on the design drawings even though they are listed as part of the distribution plan.
- Direction will need to be given to confirm if all areas will at least receive the capability to be connected, as it could be the request of a household to obtain the power connection in order to have the option of purchasing power at some indeterminate time in the future.

2.2.2 The AKF Design

AKF's Light up Bamyan project is intended to provide power to small commercial/industrial buildings and households in the Bazaar area as well as Jui Shahar, Dawodi, Zargran, and Jigrakhel villages. The area includes 1500 households and 500 small commercial or industrial buildings.

There are two refurbished generators rated 480kW and 132kW to be located in a Power House building in the bazaar to provide the power. The present drawings also include the substations, overhead and underground transmission and distribution cables, main switchboards, panelboards, and enough meters for each consumer.

All electrical installations around the UNESCO area are required to be underground, even though this is a more costly option.

AKF is estimating that 70% of the households will want to connect to the power grid after it is completed.

Below is a list of additional questions and design details to address in Task #2:

- The energy production from the 1MW photovoltaic system will not be able to provide sufficient energy for the bazaar and the four villages in the AKF design. It is therefore recommended that these two systems will commonly be operated as islands. However, the transmission line size and connection should take into account the possibility that a new substation could be available in the future to power all of the distribution system.
- The possibility of synchronizing the two supplied diesel generators with each other should be investigated.
- Determine the cost of and operational concerns with synchronizing the generators with the NZAID design.
- The various generation and distribution design teams will need to coordinate efforts and communicate with each other during the Task #2 design stage.
- To coordinate efforts, there are questions as to the placement of distribution boxes, number of homes served, and types of buildings connected that need to be addressed and or clarified.

2.2.3 The NZAID Design

The NZAID design is not complete, however what is known is that at this time a 1MW photovoltaic design utilizing 3600/kWh of battery storage is being proposed. This will need to be confirmed when the final design documents are made available.

2.3 The Mechanical Design Details

The ACEP design can be used, however there are numerous instances where primary distribution drawings (high voltage) and secondary distribution drawings (low voltage) have conflicting information as to equipment, type, size, and/or location, so the drawings will also need to be amended and altered. This will also need to occur to take into account the smaller paper size that is available in Afghanistan. Also some symbols are used that are not described in the legend, and foundation requirements are not included.

The AKF design presently includes a low voltage distribution design that utilizes different equipment specifications, and does not detail the “connection” location(s). These will likely be included by AKF in a future final design, or they may need to be included in Task #2.

The NZAID location(s) and final output voltage (400V or 20kV) will require some “connection” details, and may also require a substation design.

Once the loading per customer and locations needing service are finalized in Task #2 this could affect the conductor size, span length, sag and tension considerations, and concrete pole requirements as far as height and strength.

Finally, extended Afghan families live together, so it is possible that there will be two to five families living in one house. However, it would be impractical to install five meters on one residence. A possible solution to this problem is to have one meter, and let them decide how to divide the payments as they come due.

2.4 Environmental Impact and Mitigation

The Programmatic Environmental Assessment (PEA) will need to be completed as required by 22 CFR 216 for the total design, as this has as yet not been performed.

2.4.1 The ACEP Design

The design appears to have taken every reasonable precaution to reduce environmental impact. This is especially true with respect to the Historical and Cultural Heritage areas. However, no matter how careful the design is in these matters, it will be the construction of the system that determines the environmental impact. To that end, these ideas taken from the Public Service Commission of Wisconsin on Environmental Impact of Transmission Lines should be incorporated during the construction:

Mitigation of Agricultural Impacts
The utility should work with agricultural landowners as early in the design process as is appropriate to help identify potential impacts. , This should occur well in advance of construction. Landowners and utilities may work out solutions that include minor changes to pole heights, specific pole locations, ~~and~~ construction timing, and other significant land use concerns. By incorporating these solutions in written agreements, agricultural impacts can be prevented and/or minimized.

A utility working with landowners can:

- *Avoid or minimize construction through sensitive farmland.*
- *Identify, address, and document concerns before construction begins.*
- *Find resolutions for anticipated impacts (e.g., payments to temporarily suspend farming activities or the installation of a temporary fence).*

Problems with pole placement can be mitigated to some extent if the utility works with farmers to determine optimal pole locations.

The following approaches might be useful:

- *Using single-pole structures instead of H-frame or other multiple-pole structures so that there is less interference with farm machinery, less land impacted, and weed encroachment issues may be minimized.*
- *Locating the line along fence lines, field lines, or adjacent to roads so as to minimize field impacts.*
- *Using transmission structures with longer spans to clear fields.*
- *Orienting the structures with the plowing pattern to make farm equipment less difficult to use*
- *Minimizing the use of guy wires but where necessary, keeping the guy wires out of crop and hay lands and placing highly visible shield guards on the guy wires.*
- *Minimizing pole heights and installing markers on the shield wires above the conductors in areas where aerial spraying and seeding are common.*
- *Locating new transmission lines along existing transmission line corridors.*
- *Using special transmission designs to span existing irrigation systems or if necessary, reconfiguring the irrigation system at the utilities expense.*

The AKF and NZAID are ultimately responsible for their own environmental impact, however AKF has shown thus far that they are going to use underground cables around culturally sensitive areas, and NZAID is proposing their location as being near the airport, which is away from the culturally sensitive areas.

3.0 Conclusion

The ACEP design can be modified and adapted to meet the new requirements.

Although it is understood that the three designs (NZAID, ACEP, and AKF) were individually conceived and funded it may be possible (and definitely preferable) to make the most of the efforts thus far (assuming all parties cooperate) and synchronize the power generators on a common distribution system and not have separate islands.

Also if there are islands of electrical service that charge different rates there will be discontent, especially if the rates are substantially greater.

Because it is possible that the demand for electricity could at times exceed the supply, the ability to alternate what villages (or sections of villages) are connected to the system should be designed into the system during Task #2. This will allow the power plant operator(s) to limit the load, so that load does not exceed the capacity that the photovoltaic system or diesel generators can produce. The solution could be as simple as having a manual lockable bypass switch in strategic locations on the system.

Appendices

Appendix A: Estimated Daily Household Energy Consumption – Small House in City

Appendix A: Estimated Daily Household Energy Consumption –Small House in City

ESTIMATED DAILY HOUSEHOLD ENERGY CONSUMPTION- (SMALL HOUSE IN CITY)						
	CONTINUOUS LOADS		NON-CONTINUOUS LOADS		DAILY ENERGY CONSUMPTION	NOTES
1 ENERGY CONSUMPTION FOR LIGHTING LOADS						
	Watt	Hour	Watt	Hour	Watt-h/day	
Lighting – Living Room	60	4	60	2	360	6 hours/day (6-10PM and 4-6AM)
Lighting – Kitchen			60	2.5	150	2.5 hours/day (6-7:30PM and 4-5AM)
Lighting – Bedroom			60	2	120	2 hours/day (9-10PM and 4-5AM)
Lighting – Guest Bedroom			60	2	120	2 hours/day (9-10PM and 4-5AM)
Lighting – Bathroom			60	1	60	1 hour/day
2 ENERGY CONSUMPTION FOR RECEPTACLE OUTLET LOADS						
TV	120	4			480	4 hours/day (6-10PM)
Video Player/Radio			60	1	60	2 hours/day
3 ENERGY CONSUMPTION FOR OTHER LOADS						
Ceiling Fan – Living Room	60	3			180	3 hours/day in Living room
Ceiling Fan - Bedrooms			120	2	240	2 hours/day in Bedrooms
Estimated Daily Energy Consumption					**1,770 Wh/day**	**SMALL HOUSE IN CITY**

Appendix B: Estimated Daily Household Energy Consumption – Small House in Village

Appendix B: Estimated Daily Household Energy Consumption – Small House in Village

ESTIMATED DAILY HOUSEHOLD ENERGY CONSUMPTION- (SMALL HOUSE IN VILLAGE)						
	CONTINUOUS LOADS		NON-CONTINUOUS LOADS		DAILY ENERGY CONSUMPTION	NOTES
1 ENERGY CONSUMPTION FOR LIGHTING LOADS						
	Watt	Hour	Watt	Hour	Watt-h/day	
Lighting – Living Room	60	4	60	2	360	6 hours/day (6-10PM and 4-6AM)
Lighting – Kitchen			60	2	120	2 hours/day (6-7PM and 4-5AM)
Lighting – Bedroom			60	2	120	2 hours/day (9-10PM and 4-5AM)
Lighting – Guest Bedroom			60	2	120	2 hours/day (9-10PM and 4-5AM)
Lighting – Bathroom			60	1	60	1 hour/day
Lighting - Animal Holding			120	.50	60	.50 hours/day
Lighting - Food Storage for animals			60	.25	15	.2 hours/day
Lighting - Storage for wood			60	.20	12	.15 hours/day
2 ENERGY CONSUMPTION FOR RECEPTACLE OUTLET LOADS						
TV			120	2	240	2 hours/day (7-9PM) (50 % of HH have TV)
Video Player/Radio			60	2	120	2 hours/day
Estimated Daily Energy Consumption					**1,227 Wh/day**	**SMALL HOUSE IN VILLAGE**

Appendix C: Energy Needs and Production when Consumers use more Energy per Household

Appendix C: Energy Needs and Production when Consumers use more Energy per Household

Direction from Bamyan	Town	Distance in Meters To Bamyan	Households		Daily Energy Consumption (watt-h/day)			Average Daily Energy in kWh if 100% of consumers connect	Average Daily Energy in kWh if 25% of consumers connect (See Note 1)
			Large Houses	Small Houses	Small Houses - Village	Small Houses - City	Large House		
					1227	**1770**	**6567**		
East	Topchi	12,487		280	343,560			344	86
	Ahangaran	9,565		300	368,100			368	92
	Dar e Somerah	7,906		120	147,240			147	37
	Badmast (Fatmasty)	7,028		110	134,970			135	34
	Lolakhel	6,103		100	122,700			123	31
	Khowel	6,007		90	110,430			110	28
	Mullayan	5,538		60	73,620			74	18
	Kakharaq	5,268		180	220,860			221	55
	Haiderabad	4,800		300	368,100			368	92
	Nawabad	2,432		100	122,700			123	31
	Syadabad	1,255		300	368,100			368	92
Center	Bamyan	0	150	300		531,000	985,050	1,516	379
West	Buddha Shadow	2,023		150	184,050			184	46
	Zargadan	2,451		**800**	**By AKF**			0	0
	Jograkhel	2,842		**75**	**By AKF**			0	0
	Tamava Tajik	3,731		50	61,350			61	15
	Sorhqole	5,000		250	306,750			307	77
	Qualaya Gaymay	5,692		60	73,620			74	18
	Busana	6,477		40	49,080			49	12
	Sadat	8,626		300	368,100			368	92
	Bamsaray	10,696		150	184,050			184	46
	Mullahgoulam	12,000		280	343,560			344	86
	Sorkhdar	15,000		100	122,700			123	31
	Hajdar	15,000		300	368,100			368	92
	Chabdara	17,000		150	184,050			184	46
		Total Households:	4,070	Total Daily Energy Consumption:				6,142	1,535

DAILY ENERGY PRODUCTION BY 1 MW PHOTOVOLTAIC POWER PLANT [in kWh]									
Month	MONTHLY AVERAGED INSOLATION RATES IN BAMYAN	100%Output	90 % Output	80 % Output	70 % Output	65 % Output	Month	Additional daily kWh needed if 100% of consumers connect	Additional daily kWh needed if 25% of consumers connect (See Note 1)
April	5.47	5,470	4,923	4,376	3,829	**3,556**	April	2,587	**No deficit**
May	6.99	6,990	6,291	5,592	4,893	**4,544**	May	1,599	**No deficit**
June	7.78	7,780	7,002	6,224	5,446	**5,057**	June	1,085	**No deficit**
July	7.41	7,410	6,669	5,928	5,187	**4,817**	July	1,326	**No deficit**
August	6.8	6,800	6,120	5,440	4,760	**4,420**	August	1,722	**No deficit**
September	6.12	6,120	5,508	4,896	4,284	**3,978**	September	2,164	**No deficit**
October	4.99	4,990	4,491	3,992	3,493	**3,244**	October	2,899	**No deficit**
November	3.51	3,510	3,159	2,808	2,457	**2,282**	November	3,861	**No deficit**
December	2.53	2,530	**2,277**	2,024	1,771	**1,645**	December	4,498	**No deficit**

January	2.76	2,760	2,484	2,208	1,932	**1,794**	January	4,348	**No deficit**
February	3.48	3,480	3,132	2,784	2,436	**2,262**	February	3,880	**No deficit**
March	4.19	4,190	3,771	3,352	2,933	**2,724**	March	3,419	**No deficit**

Note 1: Recent experience at Sufyane Village is that only about 1/4 of the consumers decide to connect to the system.

Appendix D: Estimated Daily Household Energy Consumption – Small House in City with 15 Watt Lights

Appendix D: Estimated Daily Household Energy Consumption – Small House in City with 15 Watt Lights

ESTIMATED DAILY HOUSEHOLD ENERGY CONSUMPTION- (SMALL HOUSE IN CITY)							
		CONTINUOUS LOADS		NON-CONTINUOUS LOADS		DAILY ENERGY CONSUMPTION	NOTES
1	**ENERGY CONSUMPTION FOR LIGHTING LOADS**						
		Watt	Hour	Watt	Hour	Watt-h/day	
Lighting – Living Room		15	4	15	2	90	6 hours/day (6-10PM and 4-6AM)
Lighting – Kitchen				15	2.5	37.5	2.5 hours/day (6-7:30PM and 4-5AM)
Lighting – Bedroom				15	2	30	2 hours/day (9-10PM and 4-5AM)
Lighting – Guest Bedroom				15	2	30	2 hours/day (9-10PM and 4-5AM)
Lighting – Bathroom				15	1	15	1 hour/day
2	**ENERGY CONSUMPTION FOR RECEPTACLE OUTLET LOADS**						
TV		120	4			480	4 hours/day (6-10PM)
Video Player/Radio				60	1	60	2 hours/day
3	**ENERGY CONSUMPTION FOR OTHER LOADS**						
Ceiling Fan – Living Room		60	3			180	3 hours/day in Living room
Ceiling Fan - Bedrooms				120	2	240	2 hours/day in Bedrooms
	Estimated Daily Energy Consumption					**1,163 Wh/day**	**SMALL HOUSE IN CITY**

Appendix E: Estimated Daily Household Energy Consumption – Small House in Village with 15 Watt Lights

Appendix E: Estimated Daily Household Energy Consumption – Small House in Village with 15 Watt Lights

ESTIMATED DAILY HOUSEHOLD ENERGY CONSUMPTION- (SMALL HOUSE IN VILLAGE)						
	CONTINUOUS LOADS		NON-CONTINUOUS LOADS		DAILY ENERGY CONSUMPTION	NOTES
1 ENERGY CONSUMPTION FOR LIGHTING LOADS						
	Watt	Hour	Watt	Hour	Watt-h/day	
Lighting – Living Room	15	4	15	2	90	6 hours/day (6-10PM and 4-6AM)
Lighting – Kitchen			15	2	30	2 hours/day (6-7PM and 4-5AM)
Lighting – Bedroom			15	2	30	2 hours/day (9-10PM and 4-5AM)
Lighting – Guest Bedroom			15	2	30	2 hours/day (9-10PM and 4-5AM)
Lighting – Bathroom			15	1	15	1 hour/day
Lighting - Animal Holding			30	.50	15	.50 hours/day
Lighting - Food Storage for animals			15	.25	3.75	.2 hours/day
Lighting - Storage for wood			15	.20	3	.15 hours/day
2 ENERGY CONSUMPTION FOR RECEPTACLE OUTLET LOADS						
TV			120	2	240	2 hours/day (7-9PM) (50 % of HH have TV)
Video Player/Radio			60	2	120	2 hours/day
Estimated Daily Energy Consumption					**532 Wh/day**	**SMALL HOUSE IN VILLAGE**

Appendix F: Energy Needs and Production when Consumers use less Energy per Household

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Direction from Bamyan	Town	Distance in Meters To Bamyan	Households		Daily Energy Consumption (watt-h/day)			Average Daily Energy in kWh if 100% of consumers connect	Average Daily Energy in kWh if 25% of consumers connect (See Note 1)
			Large Houses	Small Houses	Small Houses - Village	Small Houses - City	Large House		
					532	**1163**	**6567**		
East	Topchi	12,487		280	148,960			149	37
	Ahangaran	9,565		300	159,600			160	40
	Dar e Somerah	7,906		120	63,840			64	16
	Badmast (Fatmasty)	7,028		110	58,520			59	15
	Lolakhel	6,103		100	53,200			53	13
	Khowel	6,007		90	47,880			48	12
	Mullayan	5,538		60	31,920			32	8
	Kakharaq	5,268		180	95,760			96	24
	Haiderabad	4,800		300	159,600			160	40
	Nawabad	2,432		100	53,200			53	13
	Syadabad	1,255		300	159,600			160	40
Center	Bamyan	0	150	300		348,900	985,050	1,334	333
West	Buddha Shadow	2,023		150	79,800			80	20
	Zargadan	2,451		**800**	**By AKF**			0	0
	Jograkhel	2,842		**75**	**By AKF**			0	0
	Tamava Tajik	3,731		50	26,600			27	7
	Sorhqole	5,000		250	133,000			133	33
	Qualaya Gaymay	5,692		60	31,920			32	8
	Busana	6,477		40	21,280			21	5
	Sadat	8,626		300	159,600			160	40
	Bamsaray	10,696		150	79,800			80	20
	Mullahgoulam	12,000		280	148,960			149	37
	Sorkhdar	15,000		100	53,200			53	13
	Hajdar	15,000		300	159,600			160	40
	Chabdara	17,000		150	79,800			80	20
		Total Households:	4,070	Total Daily Energy Consumption:				3,340	835

DAILY ENERGY PRODUCTION BY 1 MW PHOTOVOLTAIC POWER PLANT [in kWh]									
Month	MONTHLY AVERAGED INSOLATION RATES IN BAMYAN	100%Output	90 % Output	80 % Output	70 % Output	65 % Output	Month	Additional daily kWh needed if 100% of consumers connect	Additional daily kWh needed if 25% of consumers connect (See Note 1)
April	5.47	5,470	4,923	4,376	3,829	**3,556**	April	**No deficit**	**No deficit**
May	6.99	6,990	6,291	5,592	4,893	**4,544**	May	**No deficit**	**No deficit**
June	7.78	7,780	7,002	6,224	5,446	**5,057**	June	**No deficit**	**No deficit**
July	7.41	7,410	6,669	5,928	5,187	**4,817**	July	**No deficit**	**No deficit**
August	6.8	6,800	6,120	5,440	4,760	**4,420**	August	**No deficit**	**No deficit**
September	6.12	6,120	5,508	4,896	4,284	**3,978**	September	**No deficit**	**No deficit**
October	4.99	4,990	4,491	3,992	3,493	**3,244**	October	97	**No deficit**
November	3.51	3,510	3,159	2,808	2,457	**2,282**	November	1,059	**No deficit**
December	2.53	2,530	**2,277**	2,024	1,771	**1,645**	December	1,696	**No deficit**

January	2.76	2,760	2,484	2,208	1,932	**1,794**	January	1,546	**No deficit**
February	3.48	3,480	3,132	2,784	2,436	**2,262**	February	1,078	**No deficit**
March	4.19	4,190	3,771	3,352	2,933	**2,724**	March	617	**No deficit**

Note 1: Recent experience at Sufyane Village is that only about 1/4 of the consumers decide to connect to the system.

Appendix G: Solar Energy for Village Development

lages. These calculations were made in Tanzania during a 10-day workshop jointly sponsored by the U.S. National Academy of Sciences and the Tanzanian National Scientific Research Council. For a week, this workshop group (*2*) poured over calculations of the costs of performing certain village tasks (i) with diesel motors, (ii) with electricity from the Tanzanian electric grid, and (iii) with five small-scale renewable technologies. The results surprised even the experts. Each of these five technologies appeared to be now or soon competitive with diesel. A number of them compete well with the electric grid for certain village tasks. These results are valid despite the assumption that capital to build the facility costs 10 percent and must be repaid during the life of the equipment. In actual fact, a great deal of capital is often available to developing countries on far more generous terms. This is more advantageous to solar energy over the life of the project than to diesel power because capital costs of the former are high relative to operating costs while the reverse tends to be more true of diesel power. Thus, for example, it may be possible to borrow nearly 100 percent of the total life of project costs for a photovoltaic installation (since such costs consist nearly entirely of initial capital), whereas for the initial capital for diesel one could borrow only about one-eighth of the life of project costs. Hence cheap capital favors solar over diesel energy.

Of course the panelists recognized that a final determination of whether a given technology should be applied to a given village situation depends not only on the financial costs, but also on availability of resources, social obstacles, social benefits, institutional barriers, long-range power requirements, and long-range development goals. In the short time available to them, they focused on estimating financial costs of the technologies considered most likely to be applicable with the understanding that this was but a first step in the decision-making process (*3*).

Basis for Cost Comparison

A hypothetical village of 300 families was chosen as a basis for estimating the magnitude of financial investment needed. It was assumed, for these initial installations, that the needs of each family could be met, on the average, by the use of 1 kilowatt-hour per day (300 kWh total) to be applied to lighting, operation of a village television receiver, radio communications, pumping water, or grinding grain. At this rate of energy consumption, Tanzanians receiving central-station generated electricity from TANESCO (Tanzania Electric Supply Company) would pay, on the average, about 0.93 shilling (*s*) per kilowatt-hour (*4*) (the U.S. equivalent is \$0.113/kWh). It was assumed further that the 300 kWh/day could be supplied either on a 5-hour basis, that is, at the rate of 60 kW, or for 20 hours, that is, at a rate of 15 kW.

Technologies of Energy Supply

Five technologies were chosen as illustrative examples, on the basis of their immediate or short-term availability (or both) (*5*).

Photovoltaic power generators. The analysis of the cost of supplying electrical power by a solar-cell array was based on a cost estimate of \$20 (U.S.) per watt-peak (W_p). Although, in a recent large-scale purchase by the U.S. government, the cost was \$15/W_p, a cost of \$20/W_p was used in these estimates on the assumption that the more favorable price would not be available for an initial small-scale purchase.

Cost calculations are summarized in Table 2 (*6*). The size of the array needed to supply 300 kWh daily was based on World Meteorological Organization insolation data for Tanzania (*7*). These figures indicate that an array with a peak power capacity of 1 kW will produce, on the average, 5.3 kWh daily. Thus, for 300 kWh/day, a generous estimate of 60 kW_p was used. An interest rate of 10 percent per annum, the prevailing rate in Tanzania, was used to calculate financing costs. The estimated cost of energy provided by photovoltaics, 11*s*/kWh, is approximately 12 times the average current cost of electricity in Dar es Salaam, as noted above.

In view of the predicted drop in the cost of photovoltaic devices—the Department of Energy looks to a cost of \$0.50/W_p by 1985, or earlier—it is interesting to see how sensitive the electricity cost is to the array cost. For an array cost of 4.1*s*/W_p (\$0.50/W_p) the total system cost for this example would be 528,000*s* with the same battery costs assumed. The annual cost would then be 94,000*s*, and the cost of electricity 0.83*s*/kWh, or 10 percent less than the current cost of electricity from the grid. The "break-even" array cost, that is, the cost of photovoltaics that would enable electricity to be generated at the average current selling price in Dar es Salaam, would be 5.28*s*/W_p or \$0.64/W_p. Thus, the use of photovoltaic devices to generate electricity for the villages of Tanzania is likely to be economically competitive within 10 years (*8*). Moreover, for any village that wants small amounts of electricity now but is not within reach of the grid (discussed later) photovoltaic devices may already be cost effective compared with conventional alternatives.

Small-scale hydropower. In the mountainous regions of Tanzania there are many small streams and rivers with a flow of water sufficient in quantity and reliability to be considered as a source of small-scale hydroelectricity. This technology is a mature one, with devices of a variety of sizes available "off the shelf" not only in the United States, but in many other countries (*9*). With known cost figures as a basis, four cases were considered, as shown in Table 3. These four cases provide for two basic situations—one in which the needs of the village (300 kWh/day) would be supplied directly by the generator during the hours of use (that is, 60 kW), and one in which a smaller generating capacity (that is, 15 kW) would be used with storage batteries to supply the required 300 kWh/day over a period of 20 hours.

The cost calculations for these four ways of supplying hydroelectric power are summarized in Tables 4 to 6. For the purposes of this exercise, it was assumed that dams and penstocks, if needed, could be constructed with local labor and materials (timber and earth) at no significant capital costs (*10*). The water requirement estimates were based on data supplied by manufacturers of turbine or generator (or both) systems of the scale discussed. In all cases, where battery storage was required, it was assumed that the cost of the batteries would be amortized over the 6-year life expected for that subsystem, in order to allow for its replacement as needed, independent of the lifetime or amortization rates (or both) for the other equipment. As with the dams and penstocks, no cost figures were included for protective housing for batteries or power-conditioning equipment, on the assumption that locally available materials would suffice. (For all of these cases, some maintenance would be advisable. At an estimated cost of 1000*s*/month, this would add 0.10*s*/kWh to each of the cost figures.) Any of these assumptions might not be valid in specific circumstances; nevertheless the estimates show that small-scale hydroelectric installations are cost competitive with present large-scale systems—to say

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